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(54) Abstract Title
Forming an underwater trench using separate rov and trenching apparatus

(57) Apparatus for forming an underwater trench on the seabed comprises a remotely operated vehicle (ROV) (2) capable of being operated underwater, and a separate trenching apparatus (1) removably connectable to the ROV, where the trenching apparatus is capable of being connected to the ROV whilst on the seabed. Load-bearing connectors for connecting the trenching apparatus to the ROV may be included. An interface unit (3) may be used to connect the trenching apparatus to the ROV, which may provide electrical and hydraulic power to the trenching apparatus. Power may also be delivered to the ROV by the interface unit (3). The trenching apparatus and the ROV may be automatically disconnected in the event of failure. Electrical power may be fed to the apparatus via an umbilical line, which may also move the apparatus, and be able to support the weight of the apparatus. The apparatus may be used for laying cable. Water jets (15) may be used to form the trench.

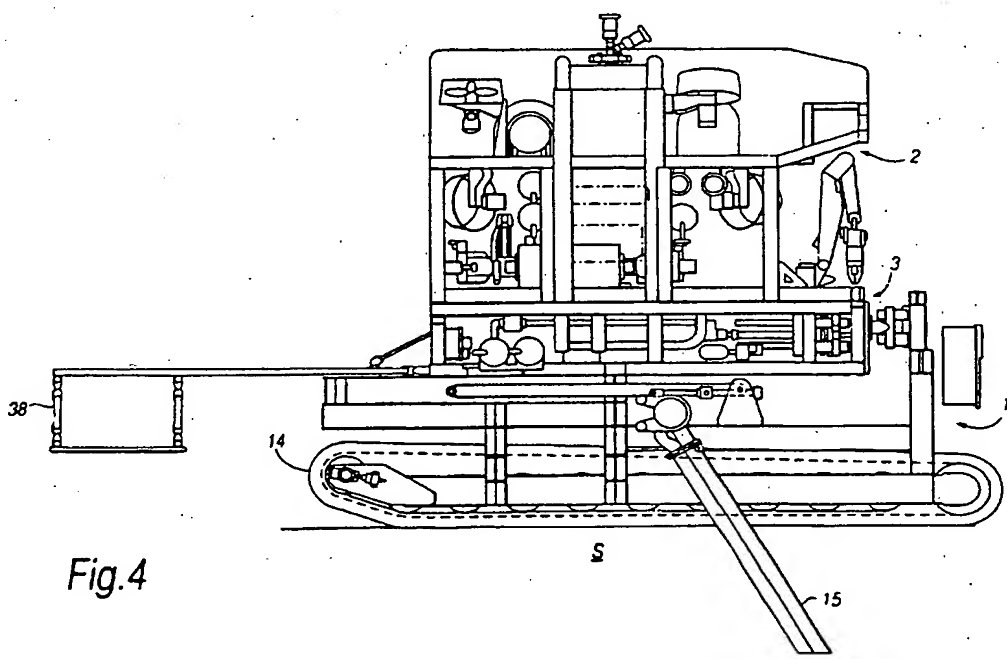

Fig.4

The claims were filed later than the filing date but within the period prescribed by Rule 25(1) of the Patents Rules 1995.
The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.
At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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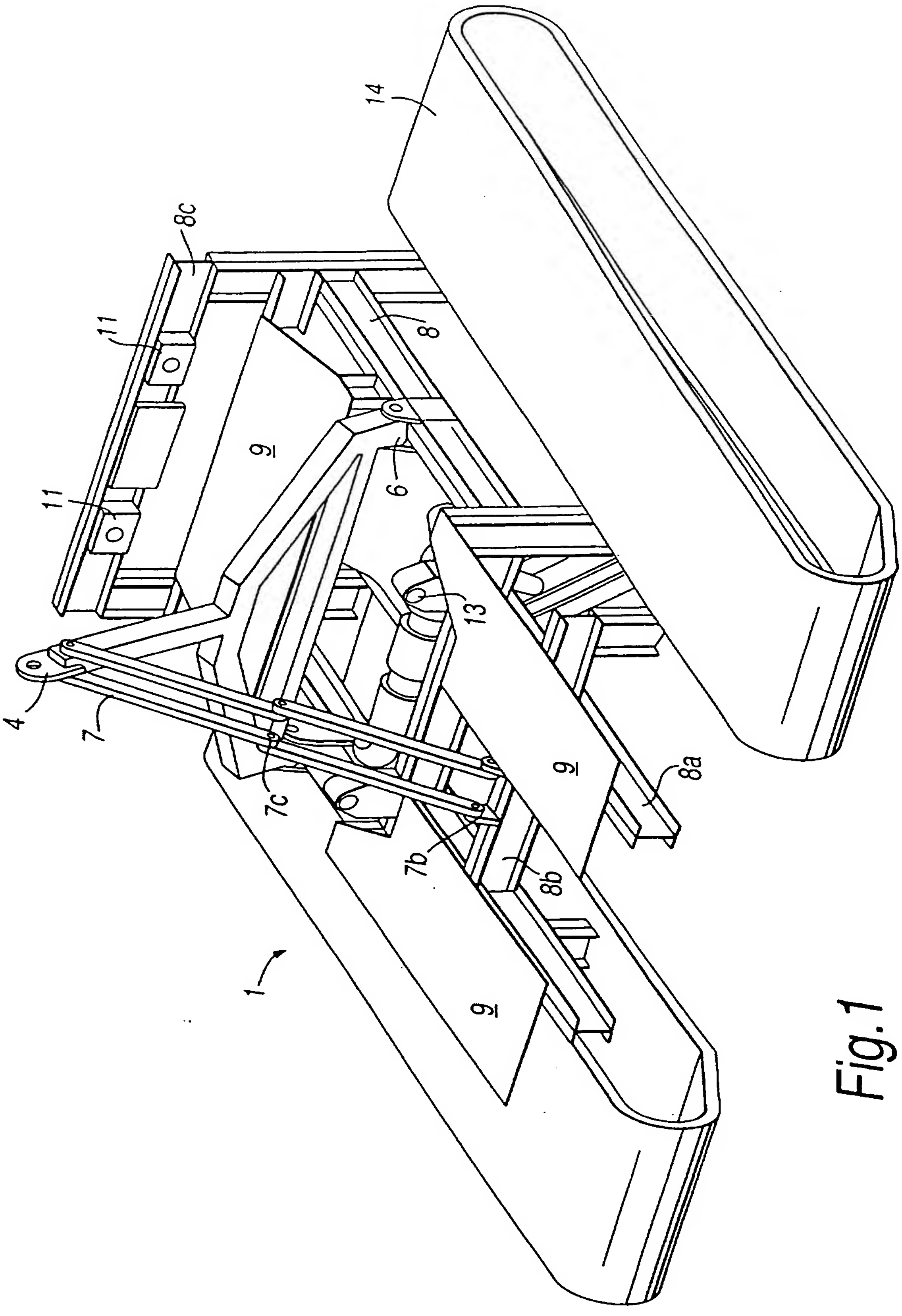

Fig.1

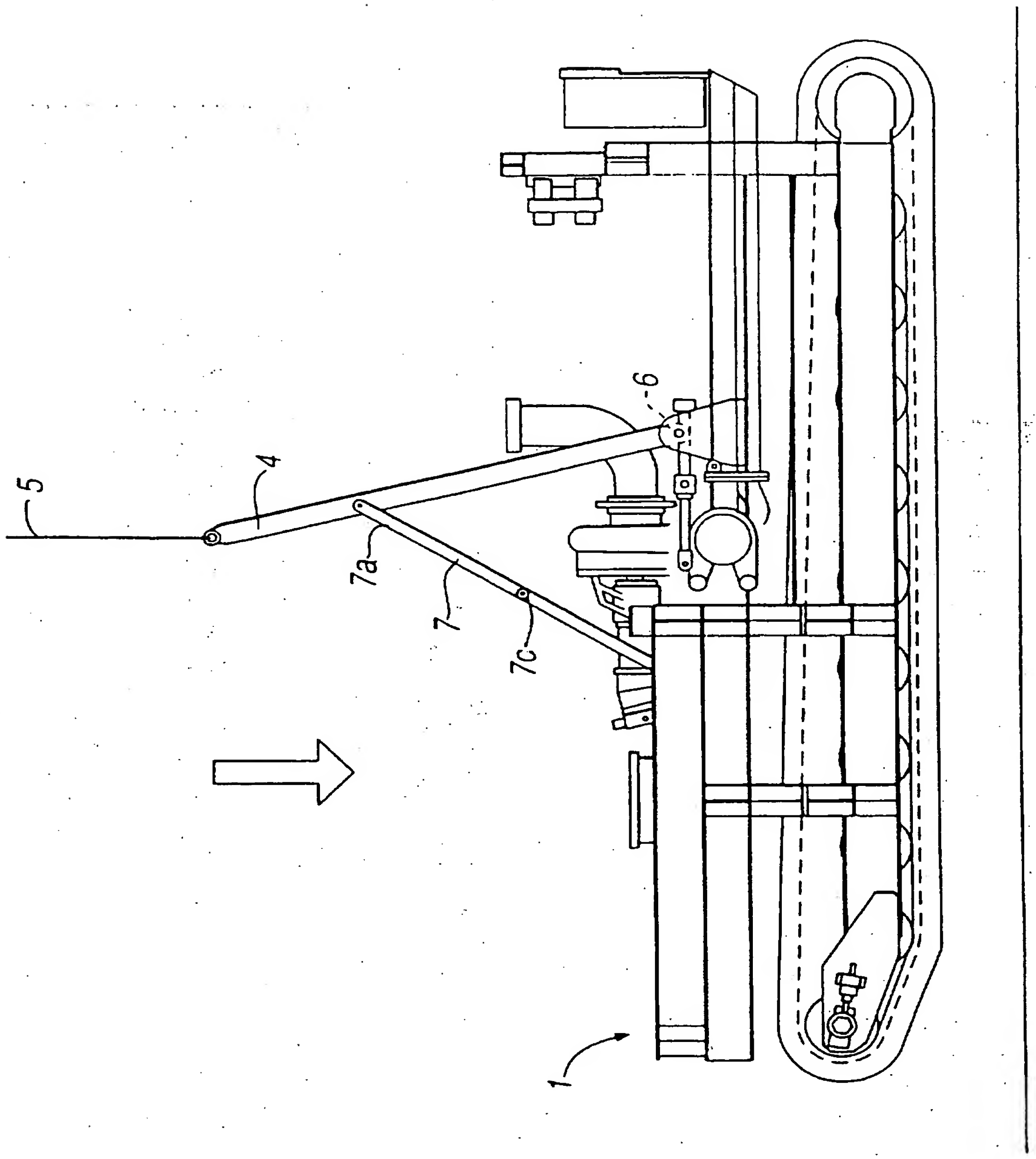

Fig.2

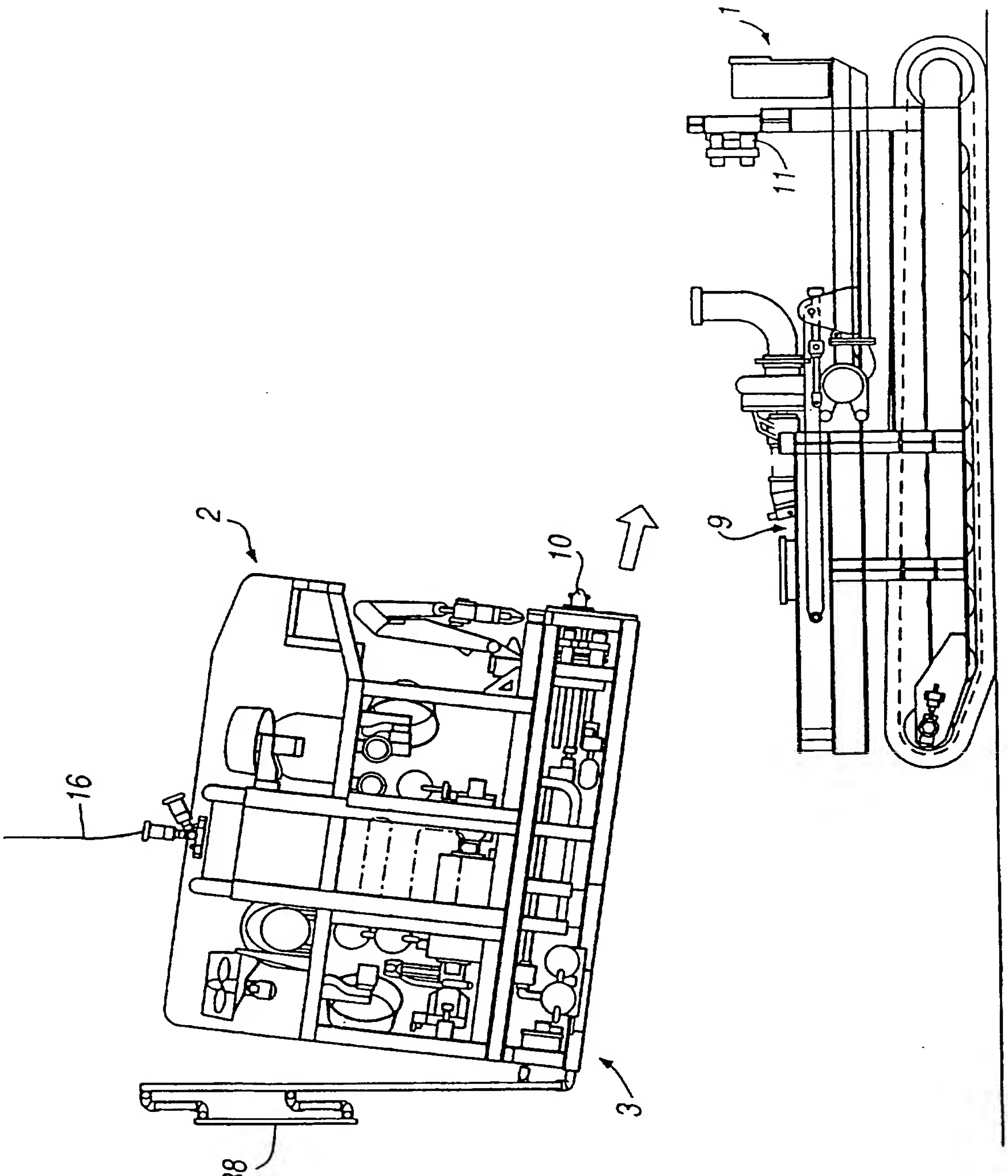

Fig.3

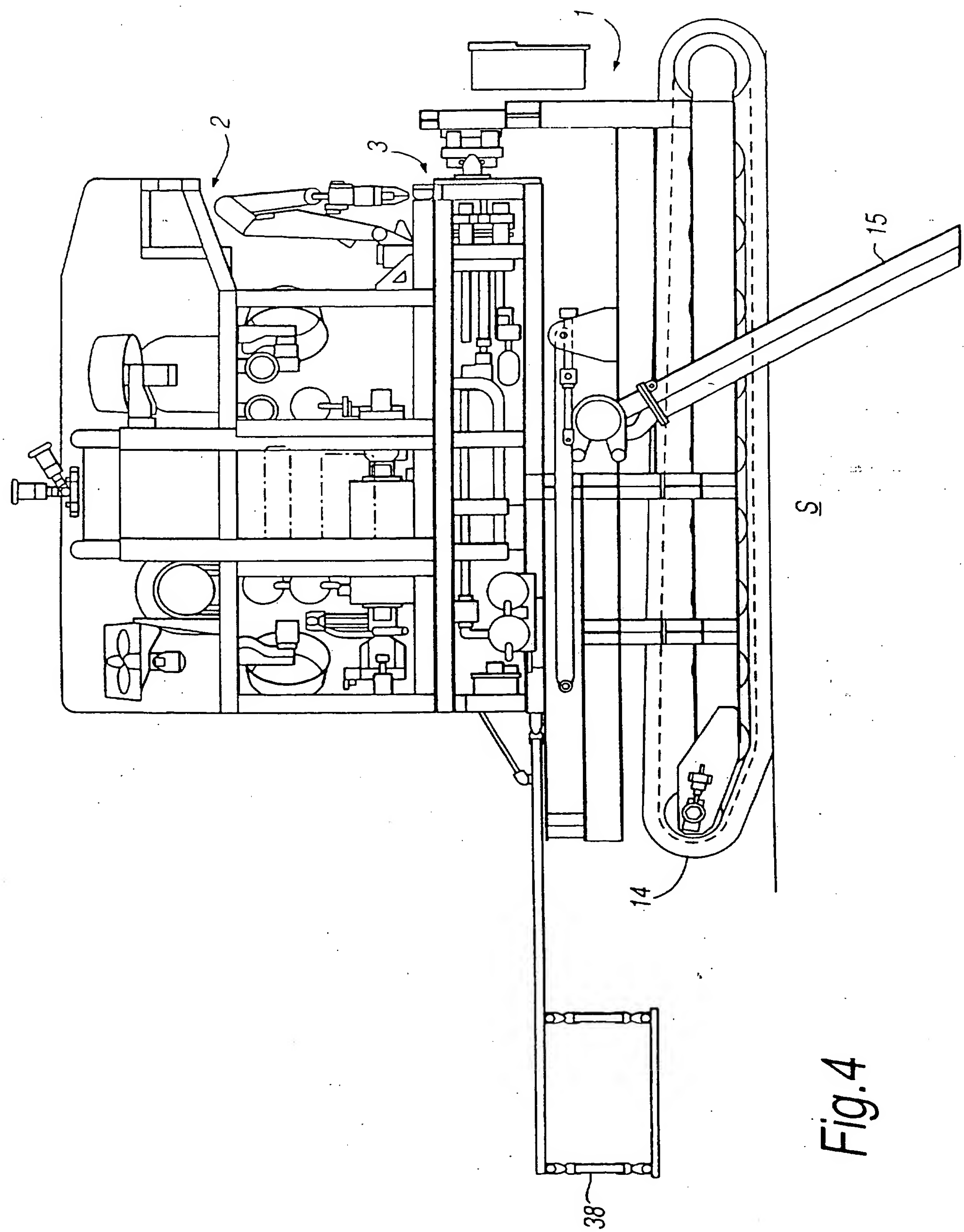

Fig.4

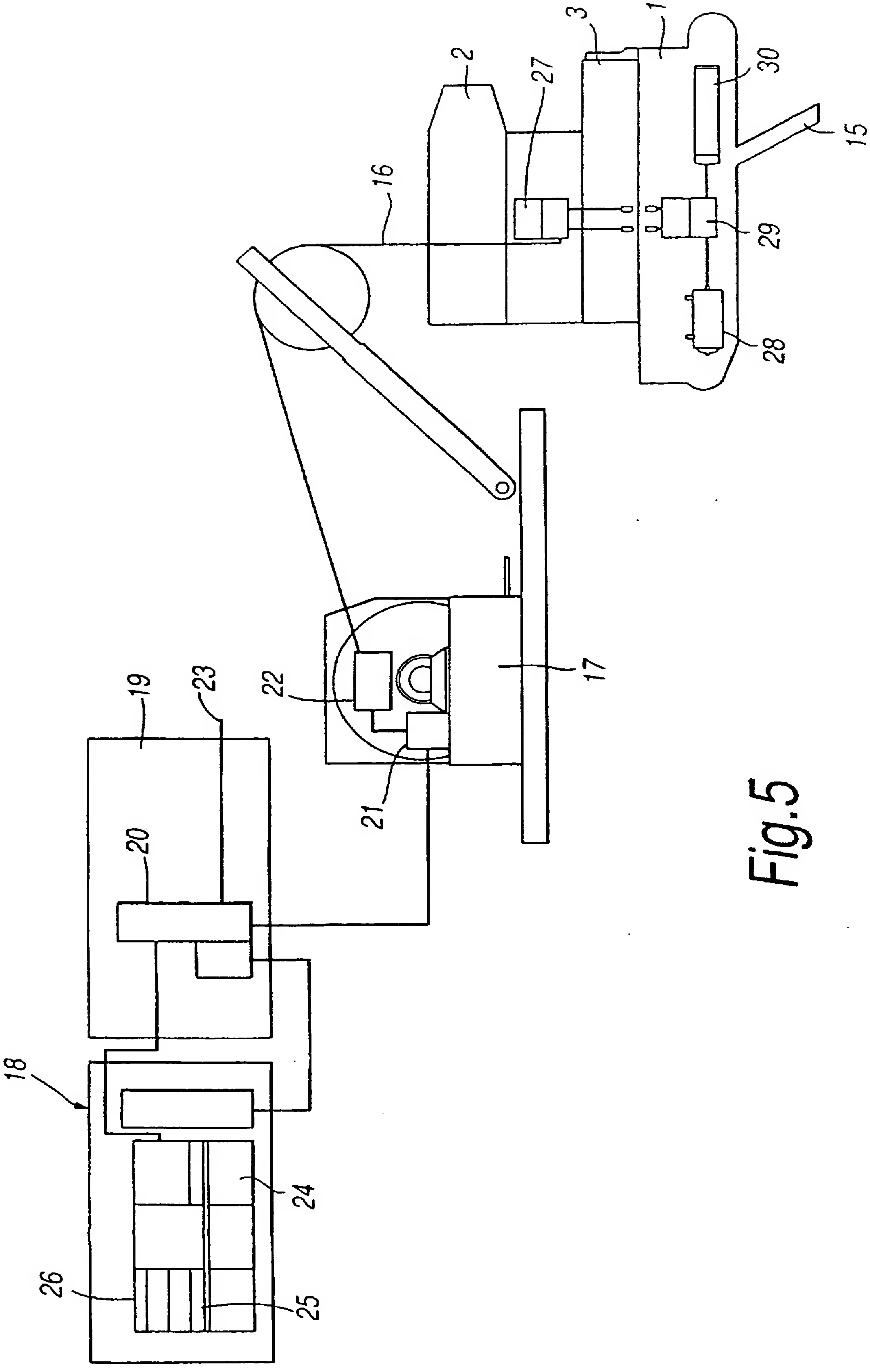

Fig.5

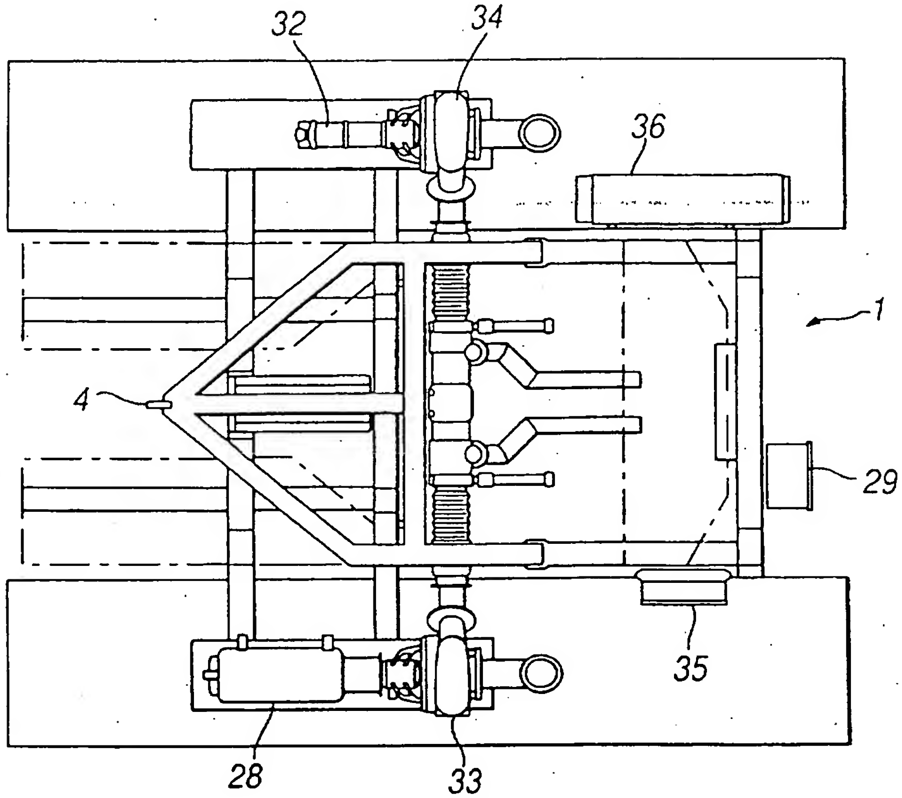

Fig.6a

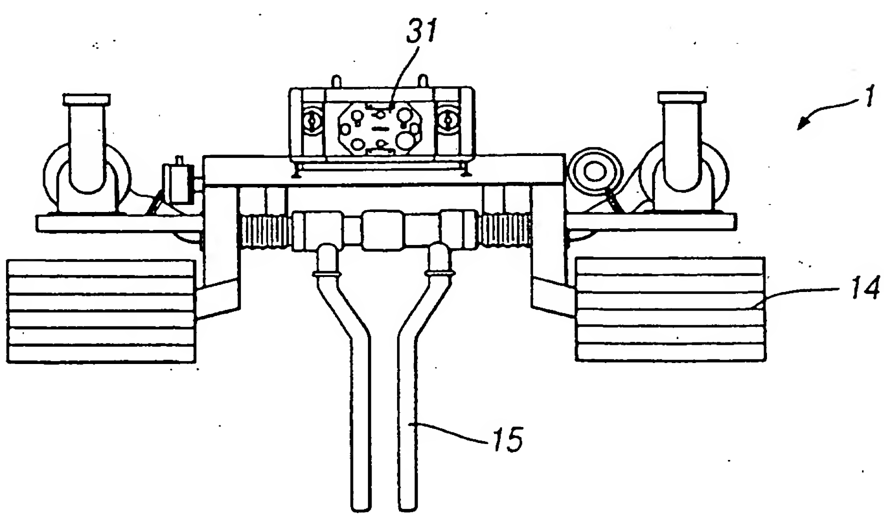

Fig.6b

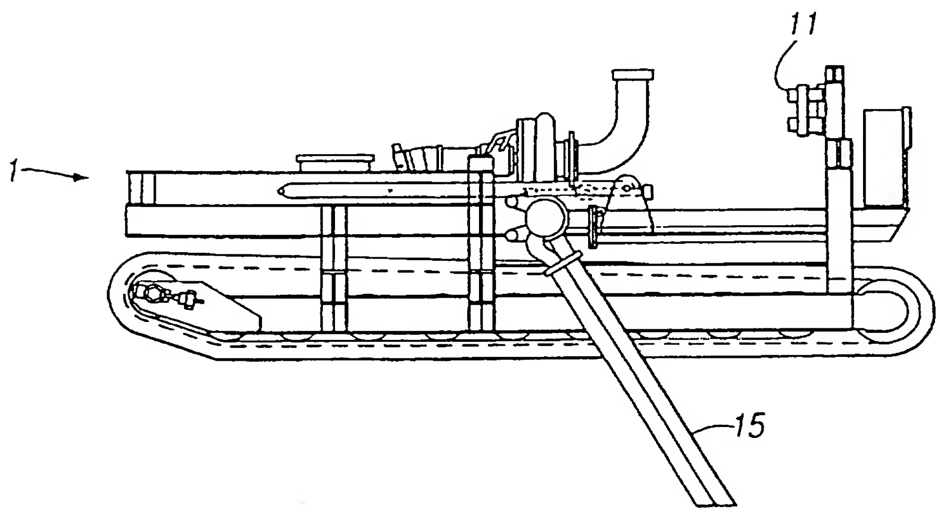

Fig.6c

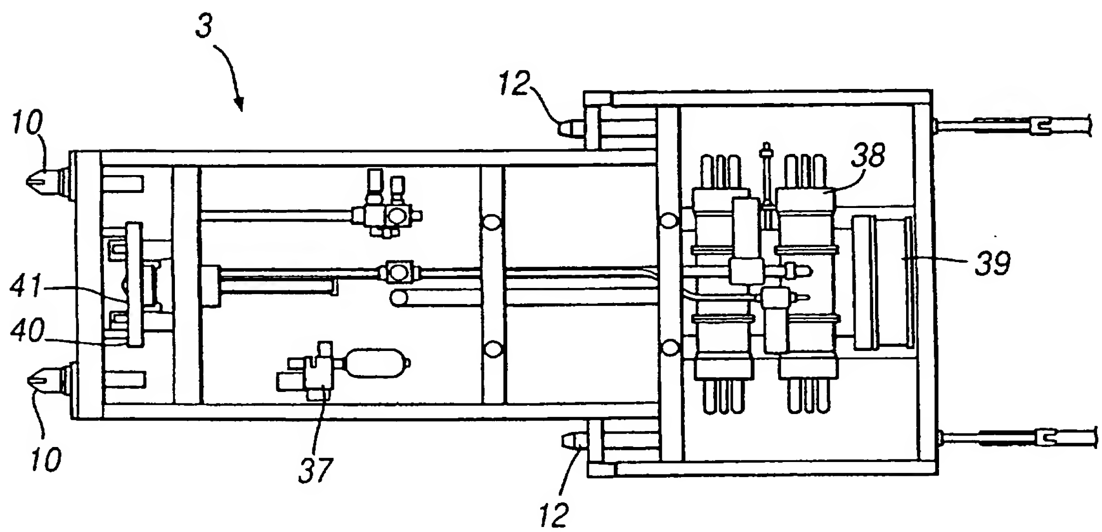

Fig.7a

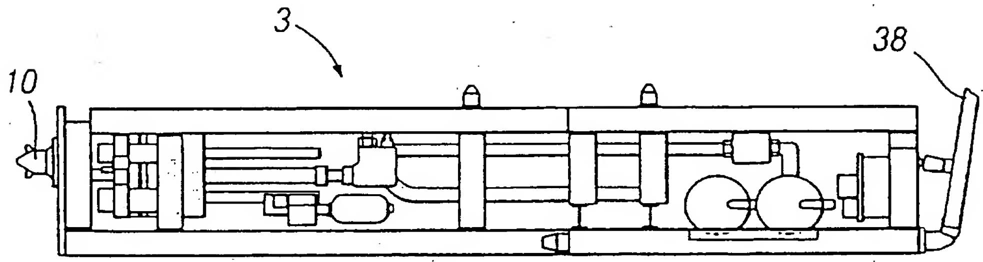

Fig.7b

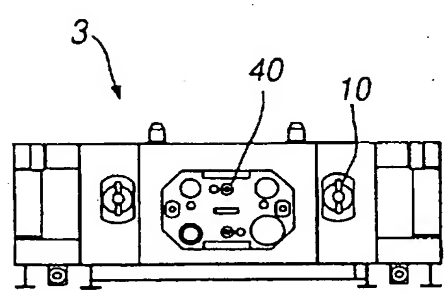

Fig.7c

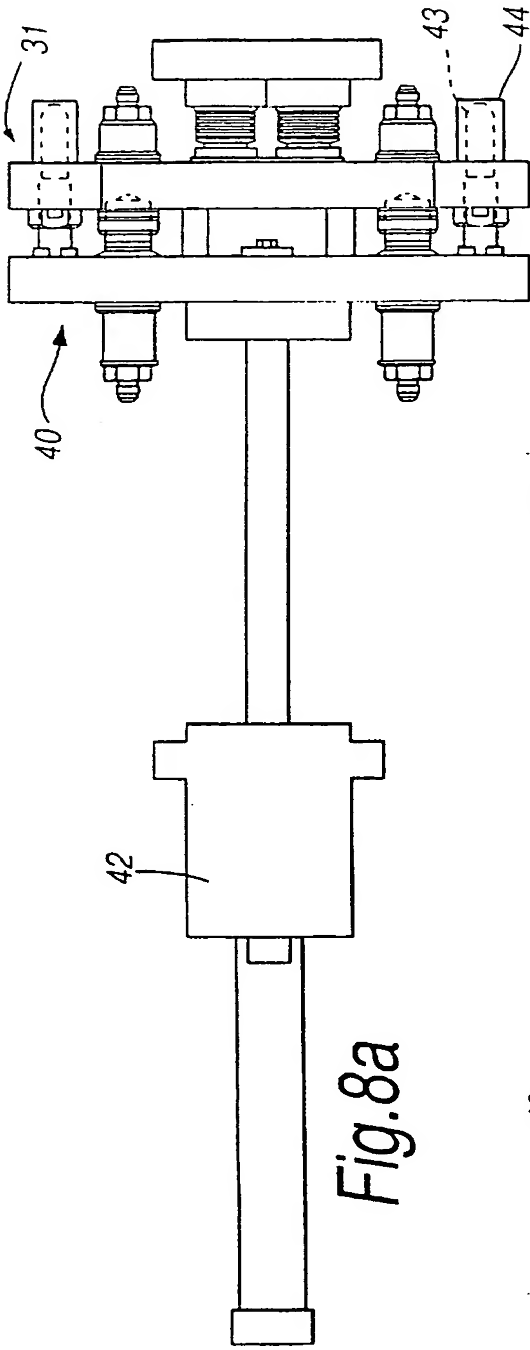

Fig.8a

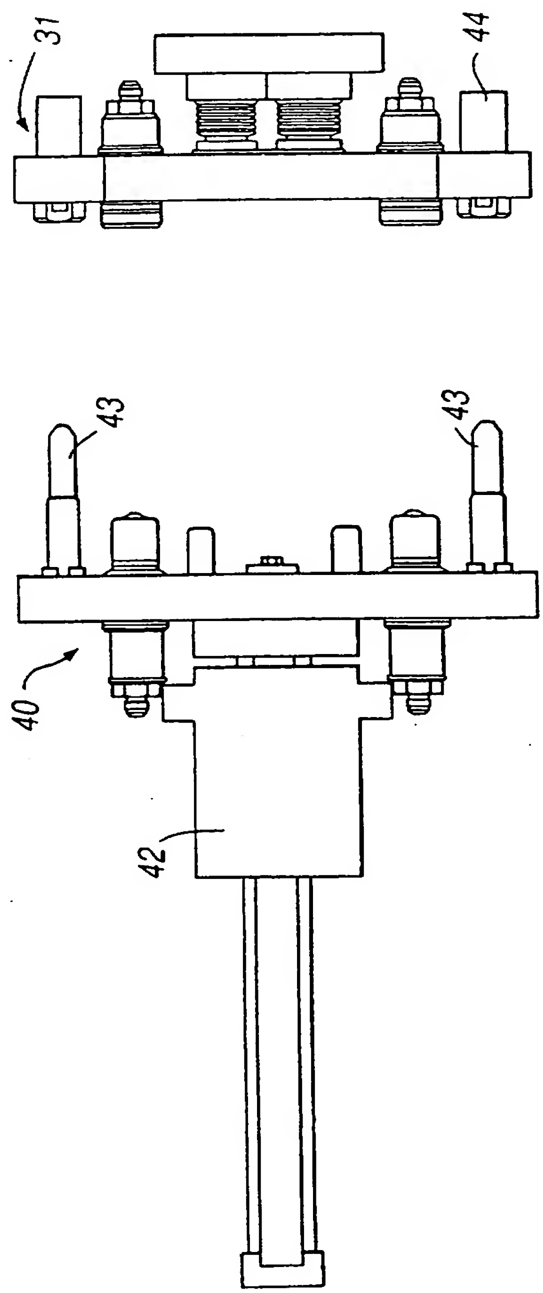

Fig.8b

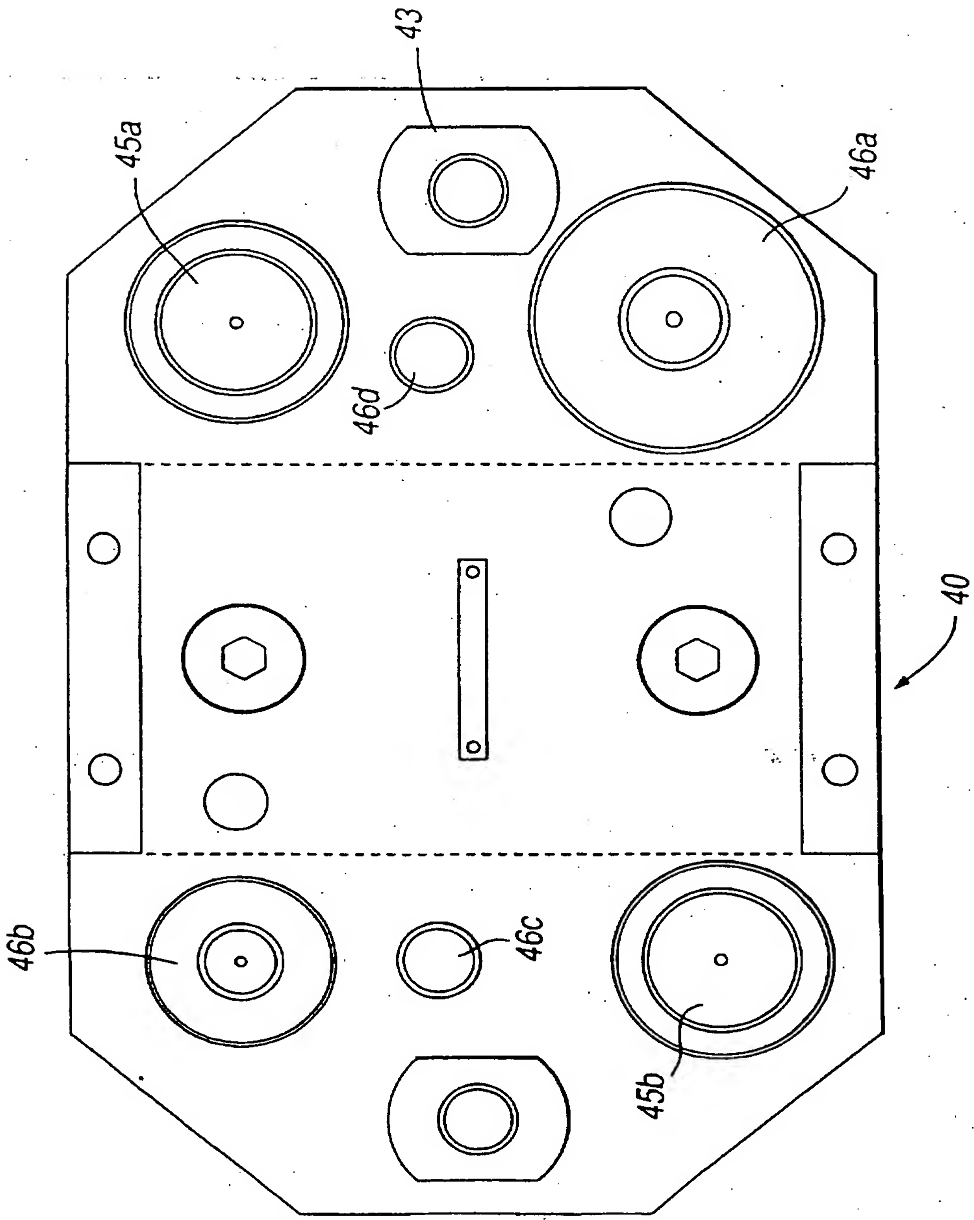

Fig.8c

Method and apparatus for forming a trench underwater.

The present invention relates to a method and apparatus for forming a trench underwater. The invention is particularly, but not exclusively concerned with forming a trench in the seabed at depths of greater than 1500m.

It is desirable to be able to form trenches in the seabed for example for receiving a telecommunications cable. Such trenches may be required in shallow water close to a coast-line but it is also sometimes desirable to form a trench at sea in a region that is a substantial distance away from the closest coast-line and/or in deep waters. Various problems arise as the depth at which a trench is to be formed increases. In deep waters, the pressure at the seabed is correspondingly higher and the physical distance between a floating vessel and the seabed is that much greater so that transfer of power from a vessel to a machine on the seabed becomes more difficult.

Methods of forming trenches may utilise a plough operated with power from a vessel fed to the plough via an umbilical line. The deeper the water, the longer the umbilical line must be and a long umbilical line itself introduces complications to a design. For example, it may be desired to pass a substantial amount of electrical power through the line and in that case the electrical conductors

in the line preferably have a relatively large cross-sectional diameter to minimise, as much as practicable, the impedance of the umbilical and therefore the power loss through the umbilical. The longer the umbilical line is made the greater the power loss will be. The impedance, and therefore the power loss, per unit length could be reduced by increasing the cross-sectional area of the conductors, but that would increase the size of the umbilical line making it more susceptible to forces from sea currents acting on the line.

Broadly, trenching machines that have been used in practice for forming trenches can be divided into two categories.

A first category may be described as purpose built trenching machines. Such purpose built trenching machines are heavy so that they have a substantial weight even when on the seabed, to enable them to bear down on the seabed and thereby achieve reasonable traction on the seabed. The need for such heavy machines to be lifted by and carried by a support vessel may determine the minimum size of vessel that can be used to transport such trenching machines out to sea; using a larger vessel leads to relatively greater operating costs. Such machines can be useful for major trenching operations but are only appropriate when a very substantial trenching operation is to be carried out.

A second category of trenching machine is not a purpose built machine but rather a remotely operable vehicle (ROV) adapted for such a purpose. Vessels used in conducting underwater tasks often carry remotely operable vehicles, which can perform many different functions. It has been proposed to provide a remotely operable vehicle arranged to be additionally capable of forming a trench, thereby removing the need for the provision of a purpose built trenching machine. However such remotely operable vehicles are of limited use in forming a trench because the remotely operable vehicle is usually designed, for the sake of its efficient use in other tasks, to have a buoyancy close to neutral buoyancy, so as to make it manoeuvrable enough to be able to perform efficiently those other tasks. When involved in a trenching operation of any kind a remotely operable vehicle has to use up a considerable amount of the power available to it in keeping the vehicle in its desired position and resisting the reaction forces applied to the vehicle as a result of the action of the trenching tool. In a purpose built heavy trenching machine such reaction forces can be absorbed simply by the traction between the machine and the seabed, but, although increasing the weight of the remotely operable vehicle would improve its function as a trenching machine, it would be detrimental to its performance of its other functions.

It has also been proposed in WO 94/24377 to connect a remotely operable vehicle to a purpose built trenching machine for operation principally in shallower water. In that case, the machine is capable of operating on its own and can be connected solely to a first umbilical line which extends between the trenching apparatus and the shore and can also be connected to a second umbilical line which extends from a remotely operable vehicle to a vessel above, the remotely operable vehicle being connected to the trenching machine. In WO 94/24377 it is proposed that the purpose built trenching machine either receives power and control signals through the first umbilical line connected to the shore or through the second umbilical line via the remotely operable vehicle; in the second case the umbilical has a multiplicity of circuits to provide power to both the remotely operable vehicle for its usual operation and to the trenching machine when it is connected to the remotely operable vehicle.

The present invention seeks to provide an improved method and apparatus for forming a trench in the seabed that mitigate at least some of the above-mentioned disadvantages with the known proposals.

According to the present invention there is provided a method of forming a trench at sea on the seabed comprising the steps of providing a remotely operable vehicle capable

of being operated underwater, providing a separate trenching apparatus removably connectable to the remotely operable vehicle, connecting the trenching apparatus to the remotely operable vehicle to form an operative trenching system, the connection being capable of being made while the trenching apparatus is on the seabed, and operating the trenching system to form a trench underwater.

In the description below with reference to the drawings one particular example of an especially advantageous method is provided. In that method various highly advantageous features which may be employed individually or in combination are described and some of those will be referred to below before describing a particular example of the invention.

Some of the components required for the operation of a purpose built trenching machine are also provided on a conventional remotely operable vehicle. In accordance with an especially advantageous feature of the present invention it is not necessary to provide such components on the trenching apparatus in addition to providing them on the remotely operable vehicle. In its most preferred form the trenching apparatus is not intended to be operated independently of the remotely operable vehicle and therefore any duplication in function present when providing a remotely operable vehicle and a separate purpose built

trenching machine may be removed when using the method of the present invention, resulting in a possible overall saving in manufacturing costs and/or a possible reduction in the total mass of the components provided for performing the functions of a conventional remotely operable vehicle and a conventional purpose built trenching machine.

The connecting of the trenching apparatus to the remotely operable vehicle is preferably conducted underwater, and may conveniently be conducted while the trenching apparatus is on the seabed. Since the remotely operable vehicle will in most cases already be underwater, much time can be saved by enabling the remotely operable vehicle to be connected to the trenching apparatus underwater. The connection of the remotely operable vehicle to the trenching apparatus in deep water may appear undesirable because of the challenges posed by the desirability of providing a connection that is mechanically strong and, in preferred embodiments of the invention, able to transmit large amounts of electrical and hydraulic power. We have found, however that it is possible to provide a satisfactory connection and that, with the benefit of certain advantageous features referred to below, an especially good connection can be made.

The remotely operable vehicle is conveniently mounted on top of the trenching apparatus. The trenching apparatus

preferably has a region at least partly on its upper surface that is arranged to receive the remotely operable vehicle either directly, or indirectly via another component of the trenching system, such that the remotely operable vehicle and trenching apparatus may be connected together. An especially advantageous feature of the invention is that the trenching system is arranged so that the remotely operable vehicle is able to support the entire weight in water of the trenching system. It is then possible for the trenching system to be lifted by an umbilical or lifting cable connected to the remote operated vehicle. There may be a plurality of mechanical connectors that facilitate and enable the trenching apparatus to be connected to the rest of the trenching system (i.e. to be connected either directly or indirectly to the remotely operable vehicle), and the connectors may include one or more load bearing connectors whereby most of the load owing to the mass of the trenching apparatus that is transmitted via the remotely operable vehicle if the system is lifted via the remotely operable vehicle is transmitted through the load bearing connectors. Preferably, substantially all of the load owing to the mass of the trenching apparatus is transmitted through the load bearing connectors. Preferably, not all of the mechanical connectors need bear any substantial load. For example, there may be four mechanical connectors, only

two of which are arranged to be load bearing connectors. The other two connectors may serve to assist correct location of the remotely operable vehicle on the trenching apparatus.

The remotely operable vehicle may have a mass that is sufficiently low to enable it to be manoeuvrable in the sea to perform the other tasks that may be demanded of it and the trenching apparatus may be sufficiently heavy that the combined weight of the remotely operable vehicle and the trenching apparatus is great enough for the purposes of forming a trench in water with the trenching system bearing down on the seabed. A typical mass for the ROV is four tonnes. The mass of the trenching apparatus is preferably greater than two tonnes and may be greater than four tonnes. The weight in water of the trenching apparatus is preferably greater than 20 kN and may be greater than 30 kN. The remotely operable vehicle is therefore preferably able to sustain the loads that would be imposed if the weight in water of the trenching apparatus were 20 kN and is more preferably able to sustain the loads that would be imposed if the weight in water of the trenching apparatus were 30 kN. The remotely operable vehicle may be able to sustain and/or be able to carry loads weighing over 100 kN. The combined mass of the remotely operable vehicle, trenching apparatus and any other components on the remotely operable

vehicle and trenching apparatus necessary for their operation or connection is preferably less than 15 tonnes.

The remotely operable vehicle may be connected to the trenching apparatus via an interface unit. The interface unit is preferably removably mounted on the remotely operable vehicle to enable the vehicle to perform other functions without the interface unit or with some other interface unit. The interface unit may be so configured that a conventional remotely operable vehicle may be used with little or no modification in the method according to the present invention. The interface unit can be connected to the remotely operable vehicle before the trenching apparatus is connected to the remotely operable vehicle via the interface unit. The interface unit may therefore be connected to the remotely operable vehicle above water. The interface unit advantageously provides not only a mechanical connection between the trenching apparatus and the remotely operable vehicle, but also an electrical and/or hydraulic connection between the trenching apparatus and the remotely operable vehicle. Parts of the mechanical connectors and/or the load bearing connectors mentioned above may be provided on the interface unit. The design and operation of the interface unit is especially significant in providing an advantageous connection between the interface unit and the trenching apparatus.

The interface unit preferably includes a connector plate. The connector plate advantageously includes all the connections required to transmit electrical and/or hydraulic power between the trenching apparatus and the remotely operable vehicle, other parts of the interface unit being able to facilitate load bearing mechanical connection between the remotely operable vehicle and the trenching apparatus. In order to perform all of its functions the mass of the interface unit may, for example, need to be over 200Kg. Its mass is preferably less than a tonne. The weight in water of the interface unit may be greater than 1kN. Its weight in water is preferably less than 5kN.

The interface unit preferably facilitates the transmission of data to and from the trenching apparatus via the interface unit. The data may, for example, include electric control signals, video signals or the like. Connecting the remotely operable vehicle to the trenching apparatus preferably includes two successive steps, the first step including connecting the interface unit to the trenching apparatus to provide a mechanical connection there between and the second step including making further connections between the interface unit and the trenching apparatus to enable power to be delivered from the remotely operable vehicle to the trenching apparatus via the interface unit. The interface unit and trenching apparatus

are advantageously so configured that the second step can not be completed until the mechanical connection of the first step has been successfully made. The interface unit may therefore be electrically connected underwater to the trenching apparatus in a safe and controlled manner.

In order to avoid a major problem arising and facilitate retrieval in the event of a failure in the trenching system, it is preferred that in the event of a system failure the remotely operable vehicle is automatically disconnected from the trenching apparatus. The automatic disconnection may involve reversal of the connection steps described above and the system may be arranged so that they are capable of being undertaken without any connection to the remotely operable vehicle through its umbilical.

Connecting the remotely operable vehicle to the trenching apparatus preferably includes the steps of connecting the remotely operable vehicle to the interface unit, transporting the trenching apparatus to a region on the seabed local to where the trench is to be formed, moving the remotely operable vehicle relative to the trenching apparatus so that the interface unit is so positioned to facilitate connection to the trenching apparatus, and connecting the trenching apparatus to the interface unit thereby connecting the remotely operable vehicle to the

trenching apparatus. The trenching apparatus may be transported to the seabed simply by lowering the trenching apparatus from a vessel via a line. The line may for example be in the form of a metal rope or cable. The trenching apparatus may be configured so that its weight can be supported from one or more designated load points. Preferably there is at least one such load point, which enables the trenching apparatus to be suspended on a line attached to the trenching apparatus only at that load point. Each of the one or more load points is arranged such that its position, when in use, in relation to the centre of gravity is such that the trenching apparatus may be transported in water in the orientation in which it is operated on the seabed. The one or more load points may be arranged on at least one part that is mounted on the trenching apparatus for movement from a position in which the trenching apparatus may be transported to a storage position. It may, for example, be necessary for the or each movably mounted part on which a load point is positioned to be moved to its storage position before the remotely operable vehicle is connected to the trenching apparatus. The trenching apparatus may alternatively be transported to the seabed by lowering a support frame containing the trenching apparatus from the vessel. If in such a case a line is used to lower the trenching apparatus from the

vessel, the line need not be connected directly to the trenching apparatus, but rather the line is preferably connected to the trenching apparatus via the frame.

Advantageously, the connection of the remotely operable vehicle to the trenching apparatus is performed remotely. Preferably the remotely operable vehicle performs the connection. The remotely operable vehicle may also facilitate the disconnection of the line, via which the trenching apparatus is transported to the seabed. There is therefore no need to arrange for the remotely operable vehicle to be connected to the trenching apparatus manually by, for example, a diver.

Whilst the remotely operable vehicle will be provided with an independent propelling means, the trenching apparatus is preferably provided with drive means capable of propelling the trenching system. The drive means may be arranged to propel the trenching system by engaging the seabed. In that case, the weight in water of the trenching system is preferably low enough to enable the trenching system to be reliably propelled along a seabed with low soil strength (for example, soil having an undrained shear strength of 4kPa). The trenching apparatus may, for example, be provided with tracks, for example, caterpillar tracks. Thus the means for moving the remotely operable vehicle may be chosen in consideration of its function as an

all purpose remotely operable vehicle and the drive means of the trenching apparatus may be chosen in consideration of the function of the remotely operable vehicle and trenching apparatus when connected together to form a trenching system.

An especially significant and advantageous feature of the invention is that during operation of the trenching system some of the power that would usually be employed by the remotely operable vehicle is passed to the trenching apparatus. In that way the total power requirement of the trenching system as a whole can be reduced and the demands on the umbilical reduced. The amount of power that is transferred from the remotely operable vehicle to the trenching apparatus is preferably a significant part, and is therefore preferably more than ten per cent of the total power consumed by the trenching apparatus. Preferably, during operation of the trenching system, hydraulic power generated in the remotely operable vehicle is passed to the trenching apparatus. In an example of the invention the total electric power consumed by the trenching apparatus is about 150hp (about 110kW) and the amount of hydraulic power generated in the remotely operable vehicle and passed to the trenching apparatus is also about 150hp (about 110kW). Advantageously, the drive means provided on the trenching apparatus is powered by power from the remotely operable

vehicle. Electrical and/or hydraulic power may be fed from the remotely operable vehicle to the trenching apparatus.

Electrical power is preferably fed to the remotely operable vehicle via the umbilical line from a vessel. The umbilical advantageously provides ac current to the remotely operable vehicle at a voltage of greater than 3.5kV. The voltage at which the ac current is provided to the remotely operable vehicle may be greater than 4kV. The voltage may, for example, be about 4.2kV. The electrical power supplied by the umbilical line is preferably greater than 200 hp (about 150 kW). The electrical power may for example be about 300 hp (about 220 kW). By providing electrical power at a higher voltage than is customarily used, the power loss per unit length along the umbilical line can be reduced. The cross-sectional area of the conductors can therefore be reduced, thereby reducing the mass per unit length of the umbilical, without significantly increasing the power loss by increasing the voltage at which the umbilical supplies power. It has been found that it is possible to construct an umbilical line that is able to operate at such high voltages without significantly prejudicing safety or risking short circuits in the sea. The umbilical still gives rise to power loss and as such the voltage at which electrical power is supplied to the umbilical on the vessel may need to be significantly higher than the voltage at which it is

desired electrical power is received at the remotely operable vehicle. For example if the voltage at which power is to be received at the remotely operable vehicle is to be 4.2 kV then it might be necessary to supply electrical power to the umbilical line on the vessel at a voltage of 4.5 kV (i.e. it may be necessary for the supply voltage on the vessel to be more than 5% higher than the voltage at which it is desired power is received by the remotely operable vehicle). The electrical power source on the vessel may be a three-phase power source and all three phases may be carried by the umbilical line. The umbilical line may have sufficient strength to enable it to support the combined weight of the remotely operable vehicle and the trenching apparatus when in water. The remotely operable vehicle and the trenching apparatus, when connected to each other, may then be moved in the water by means of the umbilical line.

A particularly advantageous method according to the invention is one including the steps of: disconnecting the remotely operable vehicle from the trenching apparatus; performing another operation with the remotely operable vehicle while the trenching apparatus is inoperative; reconnecting the remotely operable vehicle to the trenching apparatus; and operating the trenching system again to extend the trench underwater. The cycle of disconnecting and reconnecting the remotely operable vehicle can be

performed many times enabling trenching operations to be carried out with minimum disruption to other activities of the remotely operable vehicle and *vice versa*.

The method may comprise the steps of providing cable, positioning a length of the cable on the seabed and then forming the trench for the cable. Forming the trench after laying the cable has the advantage that the cable need not be carried by the remotely operable vehicle or the trenching apparatus. Advantageously the method is such that the trenching apparatus is not required to transport the whole or a substantial amount of the cable for which the trench is formed. For example the trenching apparatus need not be able to carry any reels of cable, or the like. The cable may be laid directly from a cable laying vessel. The trenching apparatus need not therefore perform a step of initially positioning the cable, for which the trench is formed, on the seabed. The trenching apparatus may therefore be of a simpler construction.

Whilst any suitable technique for forming the trench may be employed (including for example use of a chain cutter), the forming of the trench is preferably effected by use of water jets. High pressure water jets may be provided to disrupt the material forming the seabed in the region in which a trench is to be formed and one or more relatively low pressure jets may be provided to facilitate removal of

material from the sea-bed, thereby forming a trench. The high pressure jets may be generated by an electrically powered motor provided on the trenching apparatus. For example, the high pressure jets may be generated by a pump coupled to an electrically driven motor on the trenching apparatus. The electric power supply for the electrically powered motor on the trenching apparatus is preferably supplied from the remotely operable vehicle. The low pressure jets may be generated by a hydraulically powered motor, the hydraulic power being generated by means provided on the remotely operable vehicle. The hydraulically powered motor may advantageously be provided on the trenching apparatus. The gauge pressure of the high pressure jets is preferably greater than 4 bar and more preferably greater than 5 bar. The gauge pressure of the low pressure jets is preferably greater than 1.5 bar. The combined flow rate of the high pressure jets is preferably greater than 300 cubic metres per hour. The combined flow rate of the low pressure jets is preferably greater than the flow rate of the high pressure jets. The combined flow rate of the low pressure jets may, for example be greater than 500 cubic metres per hour.

The remotely operable vehicle may be provided with two independent hydraulic circuits, one hydraulic circuit being provided to operate at least one hydraulically powered

component provided on the remotely operable vehicle and the other hydraulic circuit being so arranged that it is able to operate at least one hydraulically powered component provided on the trenching apparatus. The hydraulically powered component provided on the trenching apparatus may, for example, be a hydraulically powered motor that generates water jets as described above. Advantageously, the hydraulic pressure in the two hydraulic circuits is generated by a single motor. The remotely operable vehicle may be so arranged that the ratio of hydraulic power of one of the two hydraulic circuits generated by the motor to the hydraulic power of other of the two hydraulic circuits can be varied during the operation of the motor. For example there may be remotely controllable valves provided that affect the variation of the ratio of power in one circuit to the other. It may be possible effectively to turn off one hydraulic circuit, allowing the other circuit to be operated at maximum power.

The remotely operable vehicle may be provided with an electric motor that is able to be operated with an a.c. electric current supplied at a voltage of more than 3kV. The electric motor is preferably able to utilise a three phase power source. The remotely operable vehicle may be provided with an electric motor that is able to be operated with an electric current supplied at a potential difference

of more than 3kV. Thus the motor may be so arranged that there is no need for an electric power transformer for connection to the motor to be provided on the ROV.

The trenching system may be such that the trenching apparatus requires an external power source to enable it to transport itself along the seabed from one location to another and/or to enable it to operate.

The invention also provides a trenching system for forming a trench underwater comprising a remotely operable underwater vehicle capable of being operated underwater, a separate trenching apparatus removably connectable to the remotely operable vehicle, whereby the remotely operable vehicle and trenching apparatus, once connected together, can be operated to form a trench underwater. The trenching system may be able to receive a removably mountable tool, such as a tool for forming a trench by means of water jets, a tool for forming a trench by means of a chain cutter or a tool for enabling the trenching system to perform the function of a mechanical excavator. The present invention also provides a kit of parts including a trenching system as described above and one or more such tools.

The present invention also provides a trenching system, a trenching apparatus, and a remotely operable vehicle each being suitable for use in the method according to the above-

described invention. The present invention further provides a kit of parts comprising a remotely operable vehicle and an interface unit suitable for use in the method according to the above-described invention.

Where the term cable is used herein it is to be understood to include within in its meaning not only conventional cables but also pipes or any other elongate flexible member for which a trench might be required on the seabed. Where references are made herein to values of voltages/powers or currents each value relates unless otherwise indicated, to the root mean square (rms) value and values of voltages of three phase sources relate to the rms potential difference between two phases.

Although the invention primarily relates to the formation of a trench underwater, it will be understood that the method of the invention also has application in any form of underwater excavation.

As mentioned above the invention is particularly, but not exclusively, concerned with forming a trench in the seabed at depths of greater than 1500m. For example, trenches may be formed with the apparatus described below at depths of up to about 3000m.

By way of example an embodiment of the invention will now be described with reference to the use of a trenching system in a method of forming a trench in the seabed, the

trenching system being illustrated by the accompanying schematic drawings, of which:

Figure 1 is a perspective view of a trenching skid,

Figure 2 is a side view of the trenching skid being lowered on to the seabed,

Figure 3 is a side view of an ROV connected to an interface skid being manoeuvred towards the trenching skid on the seabed,

Figure 4 is a side view of the trenching system formed from the ROV and the trenching skid,

Figure 5 is a schematic side view showing the control system of the trenching system,

Figure 6a is a plan view of the trenching skid,

Figure 6b is an end view of the trenching skid,

Figure 6c is a side view of the trenching skid,

Figure 7a is a plan view of the interface skid,

Figure 7b is a side view of the interface skid,

Figure 7c is an end view of the interface skid,

Figure 8a is a side view of a connector plate of the interface skid engaged with a corresponding connector plate on the trenching skid,

Figure 8b is a side view of the connector plates shown in Figure 8a but with the connector plates disengaged, and

Figure 8c shows a plan view of the connector plate on

the interface skid.

The trenching system illustrated by the attached drawings comprises a trenching skid 1, a remotely operable vehicle 2 (hereinafter referred to as an ROV) and an interface skid 3. The ROV is attached to one end of an umbilical line 16, which provides electrical power from a vessel at sea to the ROV. The ROV is removably connected to the trenching skid by means of the interface skid, thereby allowing the ROV to perform other functions on separation from the interface skid. The ROV 2 may also be used for other functions when still connected to the interface skid, the manoeuvrability of the ROV 2 not being significantly affected by the interface skid, because the interface skid is relatively light in weight. The interface skid not only provides a mechanical connection between the ROV 2 and the trenching skid, but also facilitates the transfer of electrical and hydraulic power from the ROV 2 to the trenching skid.

The method essentially comprises the steps of laying a cable on the seabed, transporting the trenching skid to a region on the seabed near to the cable, manoeuvring the ROV with its underslung interface skid connected thereto to the trenching skid, connecting the ROV to the trenching skid via the interface skid to form the trenching system, then

operating the trenching system, with power fed to the trenching system by the umbilical line connected to the ROV, to form a trench in which the cable is then positioned. The trenching system may be used to form a trench in the seabed where the sheer strength of the soil (undrained) is as great as 25 kPa. Although the ROV of the system is able to operate at depths of up to 3km, the maximum depth of water in which the system will normally be used is about 2km. The various components of the trenching system are described in more detail below.

Figure 1 shows a perspective view of the tracked trenching skid 1. The trenching skid 1 has a frame 8 comprising aluminium beams including longitudinal beams 8a and crossbeams 8b, 8c. The trenching system is assembled by first lowering the trenching skid 1 from a vessel (not shown in the drawings) to the seabed S. With reference to Figures 1 and 2, the trenching skid 1 is provided with an arm 4 from which the trenching skid may be lowered on a line 5 (a wire rope or the like) from the vessel. The arm 4 is mounted on the trenching skid on pins 6, or the like, and is able to rotate from an operative position (as shown in Figures 1 and 2) to a storage position (as shown in Figures 3 and 4). A support member 7 is, at one end 7a, rotatably mounted to the arm 4, the other end 7b of the support member 7 being rotatably mounted to the frame 8. A hinge joint 7c is

provided in the middle of the support member 7. Once the trenching skid is placed in a stable position on the seabed, the line 5 is released from the arm 4. The support member 7 then folds on itself (by means of the hinge joint 7c) and drops into a recessed storage position together with the arm 4 under the force of gravity.

The ROV 2 attached to the interface skid 3 is then manoeuvred into position in relation to the trenching skid 1 (see Fig. 3) to enable the ROV 2 to connect to the trenching skid via the interface skid. The trenching skid 1 is provided with a docking surface, including platforms 9 supported by the frame 8, for the ROV to land on. The ROV 2 including the interface skid approaches from the front of the trenching skid (the left hand side of the trenching skid as shown in Fig. 3). The ROV 2 moves downward and lands on the docking surface. The ROV 2 then moves (to the right as seen in Figures 3 and 4) to engage two docking latches 10 with two receptacles 11 on the trenching skid located on a crossbeam 8c at its rear. Guides are provided at the sides of the interface skid to assist initial coarse alignment. Final movement of the ROV (to the right as seen in Figures 3 and 4) then causes a pair of load bearing pins 12 (see Fig. 7a) on the ROV to engage respective receptacles 13 (see Fig. 1) provided on the trenching skid. The receptacles 13 are located about halfway along the interface skid (the notional

line joining the receptacles 13 being substantially directly vertically above the centre of mass of the trenching skid 1). The load bearing pins 12 provide the structural connection between the ROV 2 (including the interface skid 3) and the trenching skid 1 and enable the weight in water of the trenching skid 1 to be lifted by the ROV. The connection formed by the pins 12 and receptacles 13 can, but need not, be so strong as to enable the trenching skid to be lifted safely by the ROV *out of the water.* The two docking latches 10 are then locked in position. The mechanical connection of the ROV 2 to the trenching skid 1, via the interface skid 3, is then complete. Then and only then may the connections between the ROV 2 and the trenching skid 1 be made for the transfer of electric and hydraulic power from the ROV 2 to the trenching skid 1 via the interface skid 3. Connector plates (described later) are provided to make the connections between the ROV 2 and the trenching skid 1 for the transfer of electric and hydraulic power.

The ROV 2 is provided with a 150 horsepower (about 112 kW) electric motor/pump assembly, the motor enabling the ROV to perform a variety of functions, including propelling itself in the water. The single motor/pump assembly is arranged to power two independent hydraulic circuits. One hydraulic circuit provides power to components on the ROV 2 and the other circuit provides power via the interface skid

3 to components on the trenching skid 1. The circuits and associated systems are configured so that substantially all of the available hydraulic power generated by the motor/pump assembly on the ROV 2 can be made available to the trenching skid 1 via the interface skid 3. The interface skid 3 is provided with a valve system that facilitates control of the hydraulic power from the ROV 2 to the systems of the trenching skid 1. The main compensator 38 (see Fig 7a) in respect of the hydraulic circuit delivering power to the trenching skid from the ROV 2 is located in the interface skid 3. Oil is also delivered to the trenching skid 1 via the interface skid 3.

Hydraulic power fed to the trenching skid 1 from the ROV 2 drives, amongst other components, the tracks 14 of the trenching skid. The tracks 14 comprise nylon pads bolted on a conventional caterpillar chain. The tracks 14 have relatively large bearing areas, to enable the trenching system to operate on the seabed where the soil strength (undrained shear strength) is low. The tracks 14 are driven by hydraulically powered motors coupled to reduction gears. The motor speed is monitored. The track system and associated frame are of relatively light construction. The trenching skid is able to be driven at speeds of above 1km per hour (when not forming a trench).

The trenching skid is fitted with a jetting tool able

to form a trench by means of pressurised fluid jets. The jetting tool comprises two arms 15 that generate forward jets under high pressure (an operating differential pressure of 6 bar) to cut a trench by fluidising soil. The combined flow rate of the high pressure jets is about 500 cubic metres per hour. The arms also generate rear jets at a lower pressure (an operating differential pressure of 1.8bar) to wash the fluidised soil out of the trench. The combined flow rate of the low pressure jets is about 700 cubic metres per hour. Electric power from the ROV 2 (fed to it by the umbilical 16) drives a 150 horsepower (about 112 kW) electric motor/pump assembly 28, 33 (see Figs. 6a to 6c) on the trenching skid that generates the high pressure jets. Hydraulic power from the ROV 2 drives a hydraulic motor 32 and a pump 34 (see Figs. 6a to 6c) on the trenching skid 1 that generate the low pressure jets. The motors 28, 32 are mounted on the frame 8 of the trenching skid 1. Each arm is provided with fluid under low pressure for the low pressure jets and fluid under high pressure for the high pressure jets. The arms 15 are connected to a rotary joint made of two coaxial cylinders that allow both independent rotational movement to and from their operational positions (see Figs. 2 and 4, for example) and sideways movement towards and away from the sides of the trenching skid 1. The arms 15 are made primarily from stainless steel. The

movement of the jets is powered by the hydraulic power generated by the motor on the ROV 2 and fed to the trenching skid 1 via the interface skid 3.

The submerged weight of the trenching skid is preferably as low as practically possible and is about 4 tonnes. The trenching skid is, unlike many underwater machines, not provided with a variable ballast. Not having such a variable ballast has the benefits that the construction of the trenching skid is less complicated and the trenching system can operate in relatively greater depths. If necessary, it is possible to lift the whole trenching system, while the whole of the system is in water, by means of the umbilical line 16 attached to the ROV.

Figure 5 shows schematically the complete trenching system and some of the components that are provided on the vessel above water. The equipment on the vessel includes a winch 17 that controls the length of umbilical line 16 between the vessel and the ROV 2, a surface control unit 18, and a container 19. The container 19 houses a transformer and power distribution unit 20 for converting electrical power received from the vessel via supply line 23 (the supply being three-phase a.c. and the surface transformers being able to accommodate a supply varying from 380V to 480V and supplying electrical power via the umbilical 16 to the trenching system 1. Electrical power is fed to the

umbilical line 16 via a fixed junction box 21 and a rotating junction box 22 associated with the winch 17. Signals to and from the control unit 18 are also transmitted via the umbilical line 16. The control unit 18 includes an ROV control unit 24, a separate and independent trenching skid control unit 25, and a control console 26 able to convey information regarding various components of the trenching system. The trenching skid control unit 25 uses the same type of hardware as conventional control units used with conventional ROVs. The trenching system can be operated entirely from the surface via the surface control unit 18. Control signals (including data) from the surface control unit 18 are fed to an underwater control unit on the trenching system via an optical multiplexer using an RS protocol serial port in the umbilical line. For example, the valve system on the interface skid 3 may be operated from the control console 26. Monitoring signals are received via analogue and digital input channels available from the ROV. Some signals, such as signals indicating the depth, pitch, roll, and heading of the trenching system, made available by the ROV control system as analogue outputs may be acquired by the trenching skid control system.

Figure 5 also shows schematically the connection of the umbilical line 16 to the ROV 2 at a junction box 27. Power from the junction box 27 is made available via a further

junction box 29 on the trenching skid 1 to the electric motor 28 on the trenching skid 1 that generates the high pressure jets for forming the trench. Figure 5 also shows schematically that the trenching skid is provided with its own control system 30.

Figures 6a to 6c show various views of the trenching skid and illustrate the positions of its various component parts including the electric/hydraulic connector plate 31, the motors 28, 32 that power the pumps 33, 34 for generating the high and low pressure water jets, respectively, the lifting arm 4, and the junction box 29. Figure 6a also shows the location on the trenching skid 1 of a hydraulic valve pack 35 controllable from the vessel and an electronic canister 36.

Figures 7a to 7c show various views of the interface skid 3. As can be seen from Figs 7a to 7c, the interface skid is provided with two load bearing pins 12. The interface skid is also provided with a safety release accumulator 37 (associated with the safe connection of the ROV 2 to the trenching skid by means of respective connector plates) and part 38 of a cable/pipe tracking system. Towards the front of the interface skid 3 (the right hand side of Fig 7a) there is provided the main compensator 38 for the circuit providing hydraulic power to the trenching skid 1 and a hydraulic valve pack 39 controllable from the

vessel. At the rear of the interface skid 3 (the left hand side of Fig 7a) there is provided a connector plate 40 for connection to the electric/hydraulic connector plate 31 on the trenching skid and a cleaning pump 41 to facilitate cleaning of the connector plates. The weight in water of the interface skid is about 2.7 kN (its mass being about 460kg).

As mentioned above the ROV 2 is first connected mechanically to the trenching skid before the connections to enable power to be transferred are made. Connector plates 31 and 40 to effect those power connections are provided on the trenching skid 1 and the interface 3, respectively. Once the necessary mechanical connections have been made the connector plate 40 on the interface skid 3 is hydraulically driven relative to a support means 42 towards the stationary connector plate 31 on the trenching skid (see Fig 8b). Centring pins 44 on the moving connector plate 40 are accommodated by receptacles 44 on the stationary connector plate 31, facilitating correct alignment of the respective connector plates 31,40. The interface skid 3 is provided with a safety release accumulator 37 that assists the safe connection/disconnection of the connector plates. In the event of a system failure the ROV 2 is disconnected from the trenching skid 1, by automatically performing a sequence of disconnecting steps. None of the associated cabling or

pipes that are connected to the plates 31, 40 are shown in the drawings, but Figure 8c shows a plan view of connector plate 40, showing the location of the connectors housed on the plate. The plate 40 has a main three phase 4.2kV electrical connector 45a and a low voltage power (110 volts) connector 45b, the electrical connectors 45a, 45b being arranged diagonally opposite each other on the plate. The plate 40 also has four hydraulic connectors 46a to 46d (a return line 46a, a pressure line 46b, a drain line 46c for the hydraulic motor 32 on the trenching skid, and a hydraulic pump pilot control line 46d). The plate 40 also has connectors for signals for transmission of data including control signals, video images (from cameras provided on the system) and profiler information.

Once the ROV 2 has been successfully and fully connected to the trenching skid 1 via the interface skid 3 the trenching system thus formed can be operated to form a trench. The trenching system is, if necessary, moved to the position where it is desired to form a trench by means of either the tracks 14 or by lifting the whole system through the umbilical line 16. The forming of the trench may then be started and the jetting arms deployed to form the trench, the arms being rotated from their storage position to their operational position. The trenching system is moved along by means of the tracks 14 as the trench is formed, the

position of the cable ahead of the trenching system being monitored by the cable/pipe tracking system 38 on the interface skid 3. The depth of the trench may be about 1m. The cable may typically have a diameter of up to about 200mm. Once the formation of the trench and the positioning of the cable in the trench is complete the ROV is disconnected from the trenching skid, so that the ROV may, for example, be used to survey the trench formed. The trenching system is therefore manoeuvred to a location removed from the trench and then the ROV 2 and interface skid 3 are disconnected from the trenching skid 3. The separation procedure (and emergency procedure in the event of power loss) is as follows. The connector plates and the docking latches are automatically released in sequence and then a hydraulically actuated mechanism pushes the ROV 2 clear of all four docking pins/latches. The hydraulic circuit driving the mechanism is such that the docking latches can only be released after the connector plates have been disconnected. The ROV 2 and interface skid 3 and the trenching skid 1 may then be recovered by the vessel in a conventional manner.

The control system of the trenching system may have different operating modes including two operating modes ("transfer mode" or "trenching mode"), two guidance modes ("track mode" or "speed mode"), and a "reverse-steering

mode" (not available when the system is operating in the trenching mode). In transfer mode, track movements are inhibited if the jetting arms are not stowed. In track mode each track can be operated individually and spot rotation of the trenching skid is possible, motion being possible regardless of the position of the jetting arms. In speed mode, the speed of movement is changed by an accelerator joystick, a second joystick being used for steering. A dedicated command enables a change in direction. In speed mode, it is not possible to move the trenching skid backwards if the jetting arms are not in their storage positions. The reverse steering command allows the pilot to drive the trenching skid from a reverse perspective, the commands for left and right being reversed (i.e. a left command steers the trenching skid leftwards when viewed from a *rear* camera position). The reverse steering command is only available in the "transfer mode", it being inhibited in the "trenching mode". In all the above cases, if a command is requested that is inhibited, a warning message is displayed on the control console. Additional modes that may be provided include an auto-tracking mode (in which the trenching skid is steered automatically to follow the cable by means of data from the cable/pipe tracking system 38) and auto-steering mode (in which the trenching skid is steered automatically to travel in a fixed heading by means of data

from the ROV control systems) for use in the transfer mode.

Claims

1. A method of forming a trench at sea on the seabed comprising the steps of

providing a remotely operable vehicle capable of being operated underwater,

providing a separate trenching apparatus removably connectable to the remotely operable vehicle,

connecting the trenching apparatus to the remotely operable vehicle to form an operative trenching system, the connection being capable of being made while the trenching apparatus is on the seabed, and

operating the trenching system to form a trench underwater.

2. A method according to claim 1, wherein the remotely operable vehicle is able to support the entire weight in water of the trenching system

3. A method according to claim 2, wherein the trenching system comprises one or more load bearing connectors that facilitate and enable the trenching apparatus to be connected to the rest of the trenching system, whereby most of the load owing to the mass of the trenching apparatus and supported by the remotely operable vehicle is transmitted through the one or more load bearing connectors.

4. A method according to any of claims 1 to 3, wherein the remotely operable vehicle is connected to the trenching apparatus via an interface unit.

5. A method according to claim 4, wherein the interface unit is removably mounted on the remotely operable vehicle.

6. A method according to claim 5, wherein the interface unit is connected to the remotely operable vehicle before the trenching apparatus is connected to the remotely operable vehicle via the interface unit.

7. A method according to any of claims 4 to 6, wherein the interface unit includes a connector plate.

8. A method according to any of claims 4 to 7, wherein electrical power and hydraulic power are supplied to the trenching apparatus via the interface unit.

9. A method according to claim 8, wherein data is able to be sent to and from the trenching apparatus via the interface unit.

10. A method according to any of claims 4 to 9, wherein connecting the remotely operable vehicle to the trenching apparatus includes two successive steps, the first step including connecting the unit comprising the remotely operable vehicle and interface unit to the trenching apparatus to provide a mechanical connection therebetween and the second step including making further connections between the interface unit and the trenching apparatus to

enable power to be delivered from the remotely operable vehicle to the trenching apparatus via the interface unit.

11. A method according to claim 10, wherein the interface unit and trenching apparatus are so configured that the second step can not be completed until the mechanical connection of the first step has been successfully made.

12. A method according to any preceding claim, in which in the event of a system failure the remotely operable vehicle is automatically disconnected from the trenching apparatus.

13. A method according to any of claims 4 to 12, wherein connecting the remotely operable vehicle to the trenching apparatus includes the steps of

connecting the remotely operable vehicle to the interface unit,

transporting the trenching apparatus to a region on the seabed local to where the trench is to be formed,

moving the remotely operable vehicle relative to the trenching apparatus so that the interface unit is so positioned to facilitate connection to the trenching apparatus, and

connecting the trenching apparatus to the interface unit thereby connecting the remotely operable vehicle to the trenching apparatus.

14. A method according to any preceding claim, including the step of transporting the trenching apparatus to the

seabed by lowering the trenching apparatus from a vessel via a line.

15. A method according to claim 14, wherein the trenching apparatus is transported to the seabed by lowering a support frame containing the trenching apparatus from the vessel via the line.

16. A method according to any preceding claim, wherein the connection of the remotely operable vehicle to the trenching apparatus is performed remotely.

17. A method according to any preceding claim, wherein the trenching apparatus is provided with drive means capable of propelling the trenching system via tracks driven by the drive means.

18. A method according to any preceding claim, in which during operation of the trenching system some of the power that would usually be employed by the remotely operable vehicle is passed to the trenching apparatus.

19. A method according any preceding claim, wherein electrical power is fed to the remotely operable vehicle via an umbilical line from a vessel.

20. A method according to claim 19, wherein the umbilical provides ac current to the remotely operable vehicle at a voltage of greater than 3.5kV.

21. A method according to claim 19 or claim 20 including a step in which the remotely operable vehicle and the

trenching apparatus, when connected to each other, are moved in the water by means of the umbilical line, wherein the combined weight of the remotely operable vehicle and the trenching apparatus is supported by the umbilical line.

22. A method according to any preceding claim, further including the steps of:

disconnecting the remotely operable vehicle from the trenching apparatus;

performing another operation with the remotely operable vehicle while the trenching apparatus is inoperative;

reconnecting the remotely operable vehicle to the trenching apparatus; and

operating the trenching system again to extend the trench underwater.

23. A method according to any preceding claim, wherein the method comprises the steps of providing cable, positioning a length of the cable on the seabed and then forming the trench for the cable.

24. A method according to any preceding claim, wherein the method is such that the trenching apparatus is not required to perform a step of initially positioning the cable, for which the trench is formed, on the seabed.

25. A method according to any preceding claim, wherein the method is such that the trenching apparatus is not required

to transport the whole or a substantial amount of the cable for which the trench is formed.

26. A method according to any preceding claim, wherein the forming of the trench is effected by use of water jets, high pressure water jets being provided to disrupt material in the region in which the trench is to be formed and one or more relatively low pressure jets being provided to facilitate removal of material, thereby forming a trench.

27. A method according to claim 26, wherein the high pressure jets are generated by an electrically powered motor provided on the trenching apparatus

28. A method according to claim 26 or claim 27, wherein the low pressure jets are generated by a hydraulically powered motor, the hydraulic power being generated by means provided on the remotely operable vehicle.

29. A method according to claim 28, wherein the hydraulically powered motor is provided on the trenching apparatus.

30. A method according to any preceding claim, wherein the remotely operable vehicle is provided with two independent hydraulic circuits, one hydraulic circuit being provided to operate at least one hydraulically powered component provided on the remotely operable vehicle and the other hydraulic circuit being so arranged that it is able to

operate at least one hydraulically powered component provided on the trenching apparatus.

31. A method according to claim 30, wherein the hydraulic pressure in the two hydraulic circuits is generated by a single motor.

32. A method according to claim 31, wherein the remotely operable vehicle is so arranged that the ratio of hydraulic power of one of the two hydraulic circuits generated by the motor to the hydraulic power of other of the two hydraulic circuits can be varied during the operation of the motor.

33. A method according to any preceding claim, wherein the remotely operable vehicle is provided with an electric motor that is able to be operated with an a.c. electric current supplied at a voltage of more than 3kV.

34. A method according to any preceding claim, wherein the trenching apparatus requires the remotely operable vehicle to be connected to it, to enable it to transport itself along the seabed from one location to another.

35. A method according to any preceding claim, wherein the trenching apparatus requires the remotely operable vehicle to be connected to it, to enable it to form a trench.

36. A trenching system for forming a trench underwater comprising

a remotely operable underwater vehicle capable of being operated underwater,

a separate trenching apparatus removably connectable to the remotely operable vehicle, whereby the remotely operable vehicle and trenching apparatus, once connected together, can be operated to form a trench underwater.

37. A trenching system according to claim 36, wherein the system is able to receive a removably mountable tool.

38. A trenching system according to claim 37, wherein the tool facilitates the formation of the trench.

39. A trenching system according to claim 37, wherein the tool enables the trenching system to perform the function of a mechanical excavator.

40. A trenching system according to claim 36 or claim 37, wherein the trenching system is so configured as to be suitable for use in a method according to any of claims 2 to 35.

41. A kit of parts including the trenching system according to claim 37 or claim 40 and one or more of the tools referred to in any of claims 37 to 39.

42. A trenching apparatus suitable for use in a method according to any of claims 1 to 35.

43. A remotely operable vehicle suitable for use in a method according to any of claims 1 to 35.

44. A kit of parts comprising a remotely operable vehicle and an interface unit suitable for use in a method according

to claim 4 or any of claims 5 to 34 when dependent on claim 4.

45. A method of forming a trench substantially as described herein with reference to any of the accompanying drawings.

46. A trenching system substantially as described herein with reference to any of the accompanying drawings.

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Application No:	GB 9907647.3	**Examiner:**	Ben Micklewright
Claims searched:	1-46	**Date of search:**	23 June 1999

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): E1F (FWDMA FWHAL FWHAT FWHAW)

Int Cl (Ed.6): E02F (5/00 5/10)

Other: WPI, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2 009 818 A	(MARITIME) See e.g. page 2 lines 18-24, 100-109	1,4-7,10-20,22-25,33-44
X	GB 1 473 253	(MARITIME) See e.g. page 3 lines 75-91, 113 to page 5 line 7 and the figures	1,4-7,10-20,22-25,33-44

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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